eRD6 Progress Report

KLAUS DEHMELT
FOR *e*RD6
EIC GENERIC DETECTOR R&D ADVISORY COMMITTEE MEETING
JANUARY 26, 2017

Stony Brook University | The State University of New York

Consortium Summary

- eRD6 Consortium consists of
  - BNL
    - B. Azmoun, A. Kiselev, M. L. Purschke, C. Woody
  - Florida Institute of Technology
    - M. Hohlmann, A. Zhang
  - INFN Trieste
    - S. Dalla Torre, S. Dasgupta, G. Hamar, S. Levorato, F. Tessarotto
  - Stony Brook University
    - Klaus Dehmelt, Abhay Deshpande, Nils Feege, Thomas Hemmick
  - University of Virginia
    - Kondo Gnanvo, Nilanga Liyanage
  - Yale University
    - Richard Majka, Nikolai Smirnov

Consortium Summary

- Groups are working on
  - BNL
    - Mini-Drift detector; TPC/Cherenkov prototype (TPCC)
  - Florida Institute of Technology
    - Large area GEM readout with zig-zag structures
  - INFN Trieste
    - Hybrid MPGD for RICH applications
  - Stony Brook University
    - Short radiator length RICH detector
    - Large area mirror coating
  - University of Virginia
    - Large area GEM readout with u-v readout strips
    - Cr-GEM
  - Yale University
    - 3-D-coordinate GEM readout; hybrid gain structure; multi-layer gating grid
- Groups published 13 papers, preparing for two more papers

Consortium Summary

- Plans for the last period
  - BNL
    - Complete analysis of TPCC test beam efforts
    - Optimization of zig-zag pattern
    - Build new X-ray scanning device
    - Investigate candidate Ne-containing gasses for ion back flow
  - Florida Institute of Technology
    - Finish tests of small zig-zag boards
    - Finish static structural FE analysis of chamber assembly
    - Phasing out participation of post-doc A. Zhang
  - INFN Trieste
    - Start investigations of Hybrid MPGD for RICH applications
  - Stony Brook University
    - Preparation of evaporator for mirror coating
  - University of Virginia
    - Continue study of Cr-GEMs
    - Validation of new electrical U-V strip contacts
    - Complete design of frames and mechanical structure, launch fabrication of full-size U-V readout board design
  - Yale University
    - Finishing write-up of 3-D-coordinate GEM readout investigations
    - Start investigating hybrid gain structure + performing gating studies

Consortium Funding

EIC Detector R&D FY2017	PI	Proposal Name	Sub-proposals	Funding Request	Priority
eRD6		RD6 Tracking/PID Consortium: Progress Report & Funding Request		**$369,500**	
	C. Woody		Material & Supply	$10,000	
			Travel	$5,000	
			Design/Mat. New Chevron RO patt.	$10,000	
			Parts&Mat. GEM/MM operation	$10,000	
			New optics VUV spectrometer	$10,000	
	M. Hohlmann		Personnel	$100,000	
			GEM foil	$9,000	
			GEM parts	$6,000	
			Material & Supply	$2,000	
			Travel	$7,000	
	S. Dalla Torre		Personnel	$33,000	
			Travel	$12,000	
			Material & Supply	$30,000	
	K. Dehmelt/T. Hemmick		GEM foils	$5,000	
			Material & Supply	$5,000	
			Test Beam Support	$10,000	
			Travel	$5,000	
	K. Gnanvo/N. Liyanage		Material & Supply U-V strips	$10,000	
			GEM support frames	$4,000	
			Material & Supply	$3,000	
			UG student	$5,000	
			Travel	$3,000	
	A. Milov		GEMs	$10,000	
			Material & Supply	$8,400	

Requested

eRD6	Klaus Dehmelt	RD6 Tracking/PID Consortium: Progress Report & Funding Request		**$413,200**	
			Close-out eRD6 generic	$15,000	High
		Targeted R&D	TPC	$111,000	Low
		Targeted R&D	Forward Planar GEM	$197,200	Low
		Targeted R&D	Cherenkov / RICH (Trieste)	$90,000	High

Assigned

Consortium Funding

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		Targeted R&D	Cherenkov / RICH (Trieste)	$90,000	High

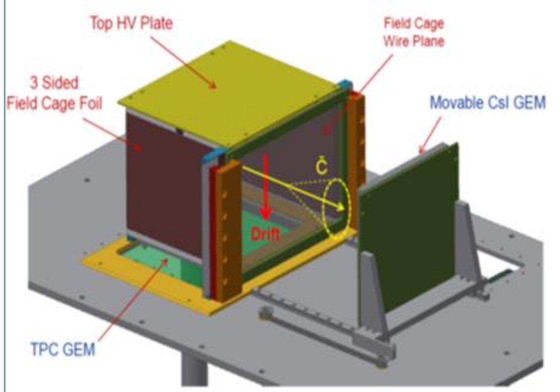
Consortium Summary

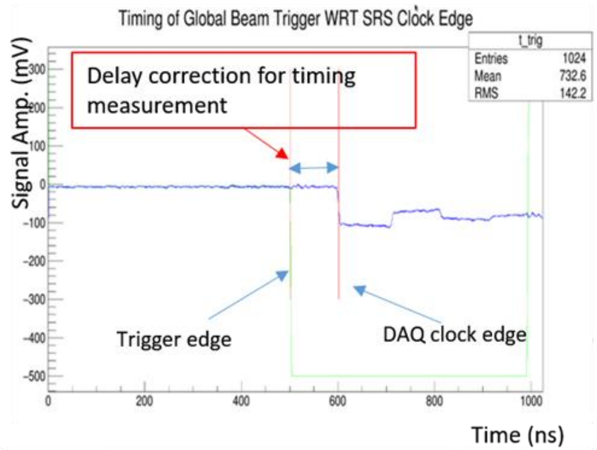
- Funding in 2016 (FY 2017)

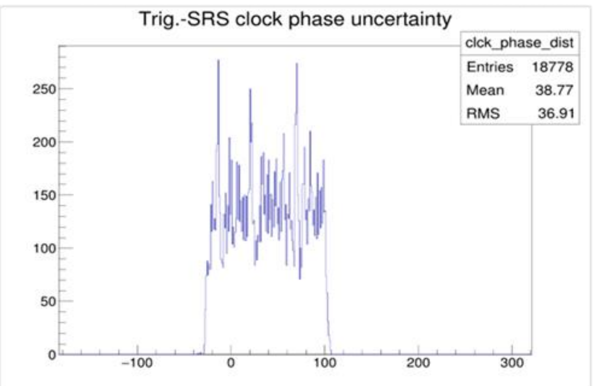
Institute	Total Request (in k$)	Funded (in k$)
BNL	67.5	15
Florida Tech	124	0
INFN	90	90
Stony Brook	40	0
UVa	30	0
WIS	18.4	0
SUM	369.5	105

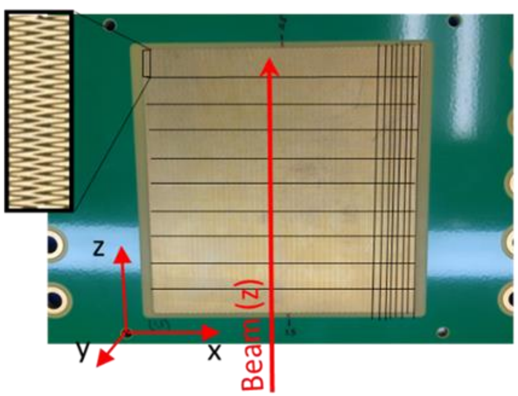
Progress @ BNL

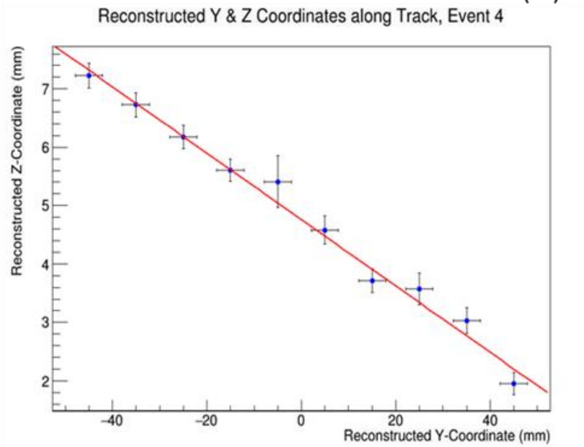
TPCC Test Beam Results

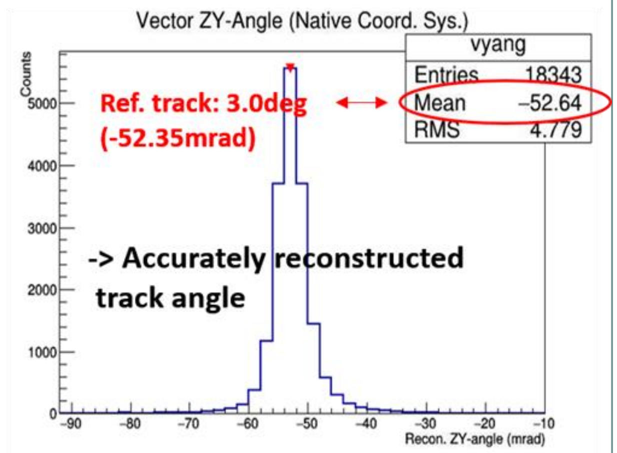












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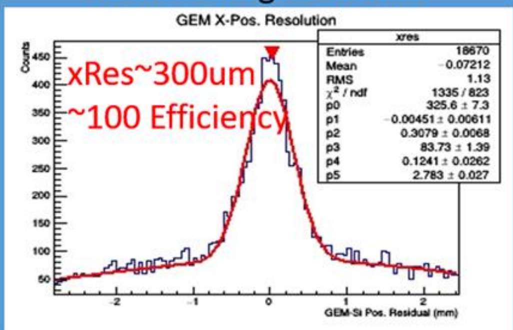
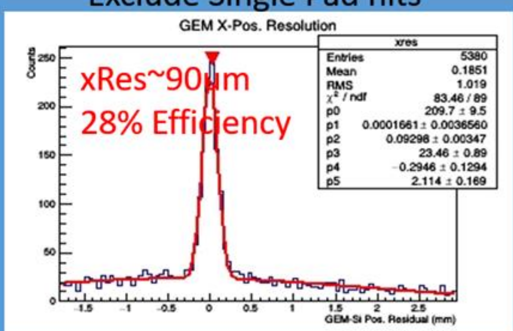
Progress @ BNL

TPCC Resolution Studies

Include Single Pad hits

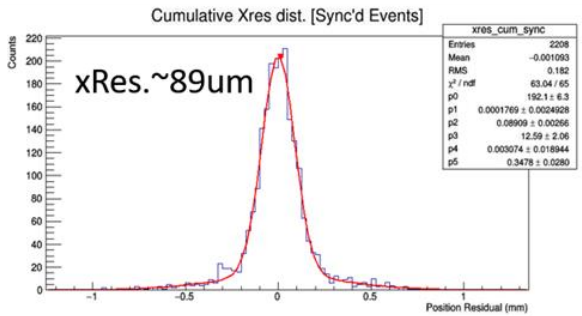


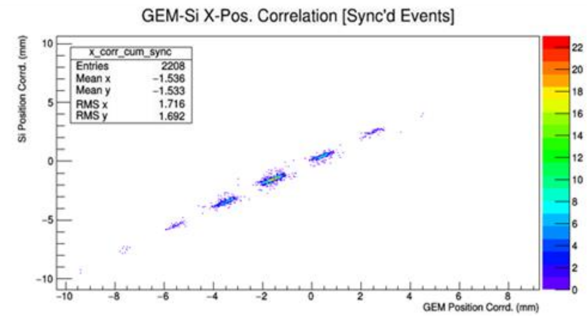
Exclude Single Pad hits

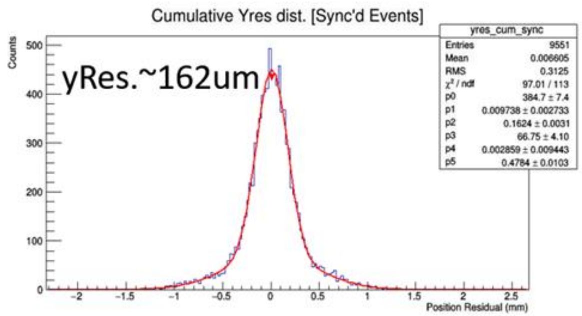


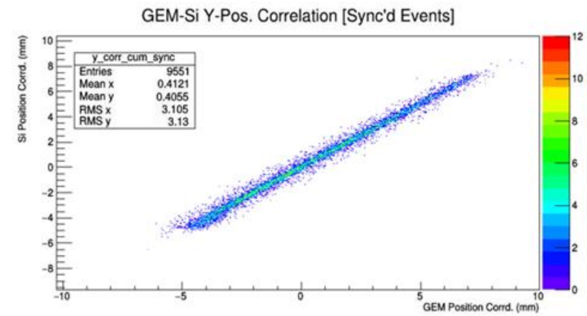
Background due to Unsynchronized events in TPCC and Si data files

Excluded single pad clusters & Synchronized TPCC and Si Data Files





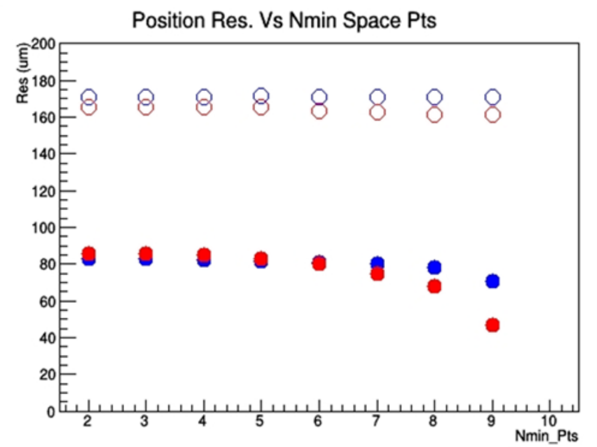


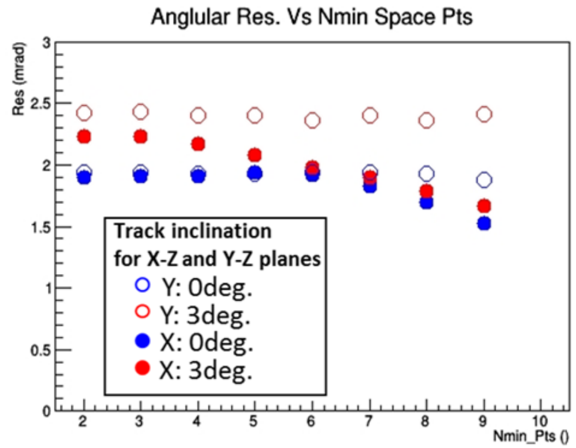


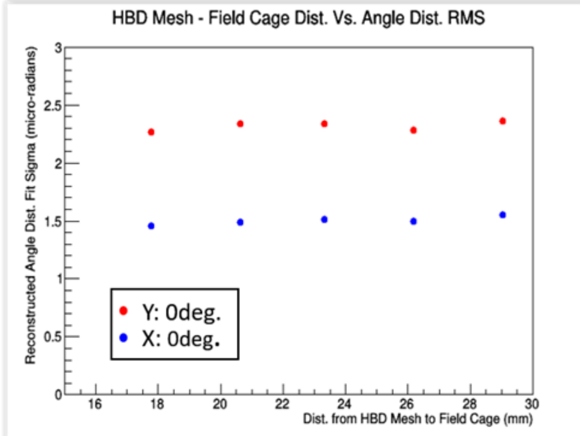
Note that the backgrounds are removed after data synchronization

Progress @ BNL

TPCC Resolution Studies







Note: The X:3deg. data series corresponds to the same data file as the Y:3deg. data, however the detector was only inclined by 3deg. along the Y-Z plane, not the X-Z plane.

- Y-vector resolution shows flat response as function of minimum number of vector points included in fit → relatively few events with less than ~8 vector points
- Significant fall-off in minimum number of vector points for → X vector is dominated by single pad hits
- Angular resolution stays fixed as a function of HBD mesh – TPC field cage distance → mesh perturbs drift field uniformity to acceptable levels in close proximity to field cage

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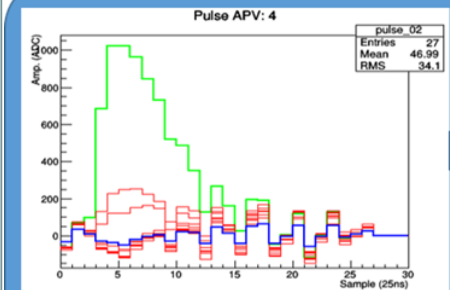
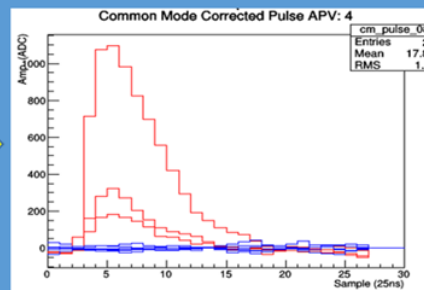
Progress @ BNL

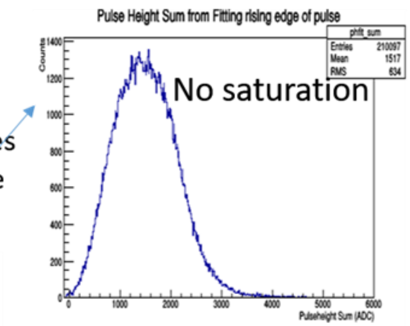
Cherenkov Radiator Length Scan



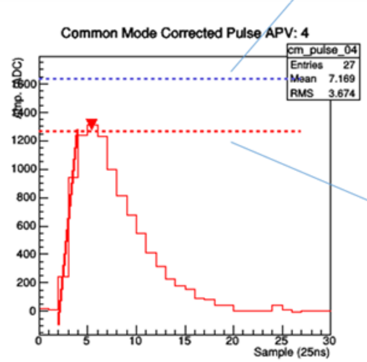


Correct raw PA pulse for common mode noise

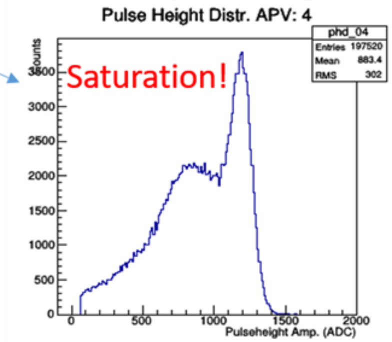
Extrapolated pulse height

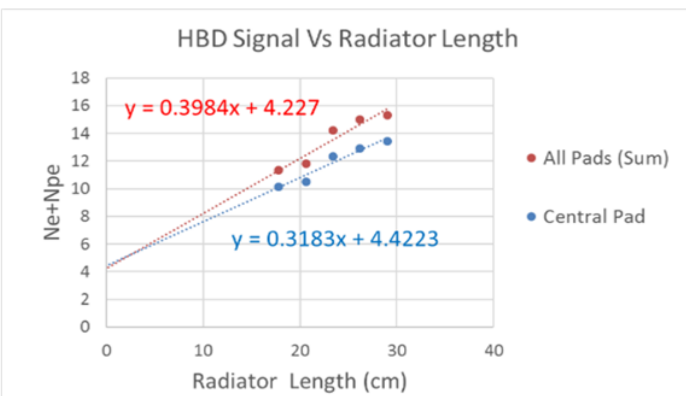


Also correct for saturated pulses by fitting to rising edge of pulse and extrapolating pule height



Standard pulse height



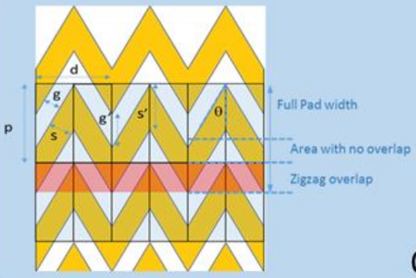


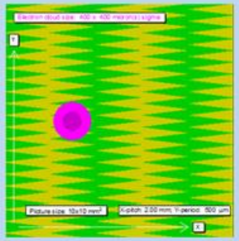
Unsaturated signal converted to Npe

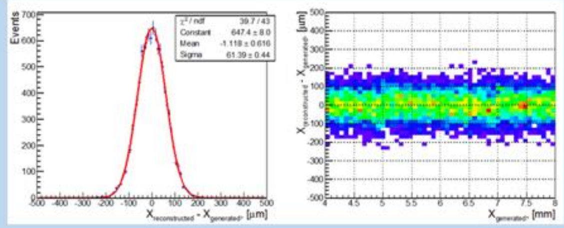
Npe corresponding to 29cm is 11.59, in very good agreement with the expected value of 11.64.

Progress @ BNL

Zigzag Pad R&D



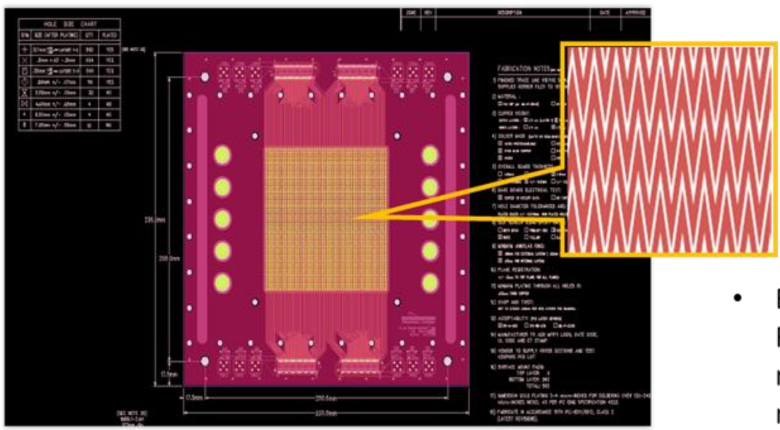




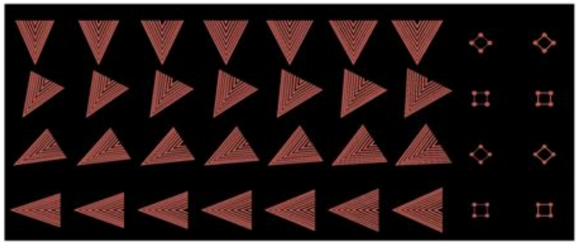
Optimize 4 ZZ parameters for best resolution using simulation

- High resolution (<100um) with relatively large pads (2x10mm)
- Minimum differential nonlinearity

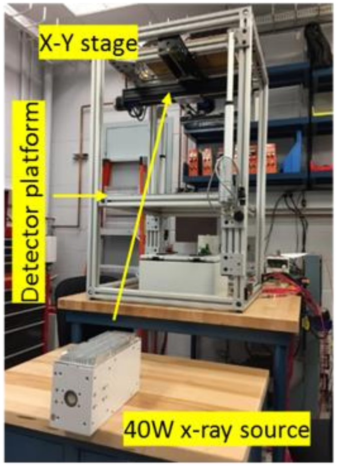
→ Maximize overlap of adjacent pads
→ Minimize gap between adjacent pads
→ **Manufacturing imposes very strong constraints on design**



PCB with optimized ZZ parameters (with 3mil gap for starters) designed and sent out for manufacture



- Building on the collaborative efforts between FIT and BNL, a main thrust of the zigzag R&D now is to push industry fabrication limits to maximize performance.
- Developed a set of test structures for testing limits of fabrication

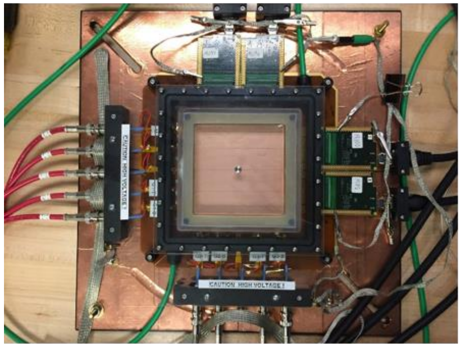


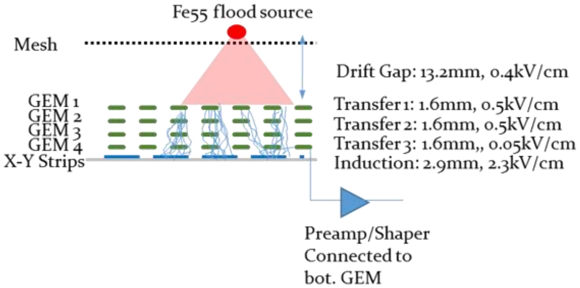
New high intensity x-ray scanner for testing ZZ patterns in the lab

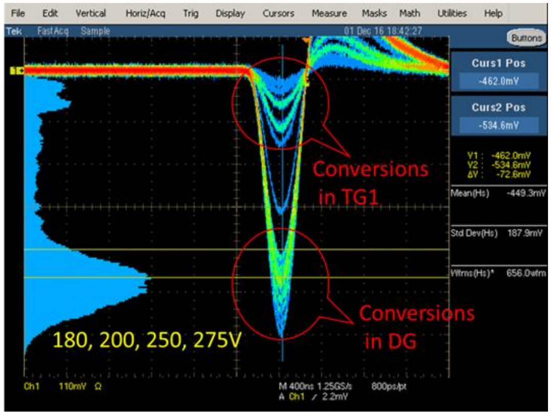
Progress @ BNL

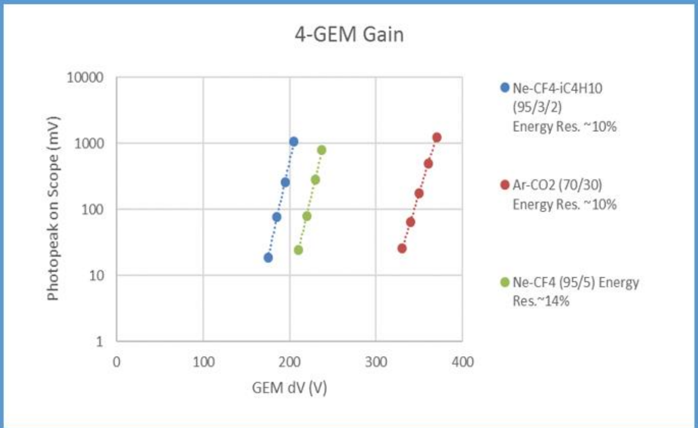
Ne-CF_4-iC_4H_{10}(95/3/2) "Ne2K gas"

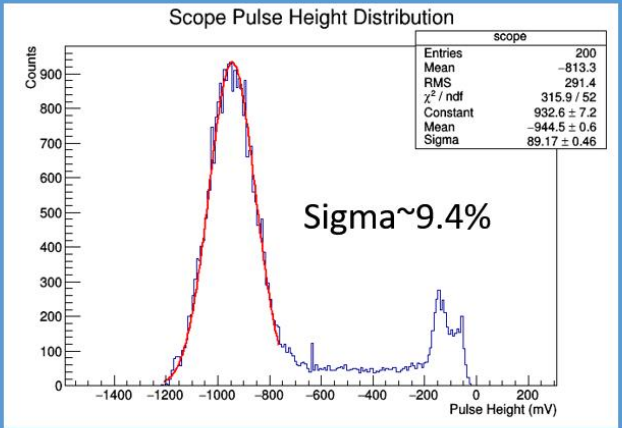
4GEM Setup









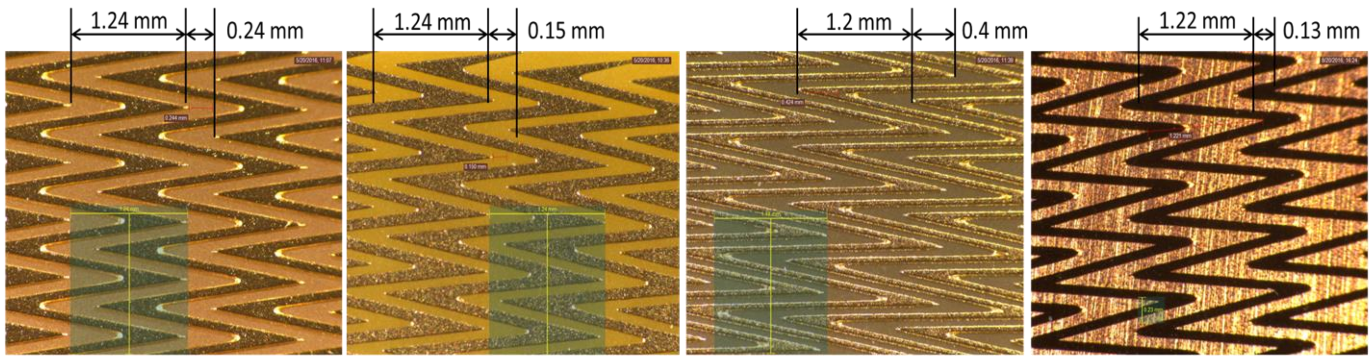


Progress @ Florida Tech

Optimization of the zigzag strip readout design
microscopic photos of zigzag structures

Best board from PCB company

Board produced at CERN; Strips are on kapton foil



ACE Board #1 Left
Interleaving: 1-(0.24/2)/1.24=**90.3%**
Copper thickness: 18 µm (1/2 oz)

ACE Board #2 Left
Interleaving: 1-(0.15/2)/1.24=**94%**
Copper thickness: 9 µm (1/4 oz)

ACE Board #3 Left
Interleaving: 1+(0.4/2)/1.2=**117%**
Copper thickness: 18 µm (1/2 oz)

CERN Board Left
Interleaving: 1-(0.13/2)/1.22=**95%**
Copper thickness: ~ 5 µm

Better zigzag design: zigzag strips interleave all the way to centers of both neighboring strips; this yields better charge sharing and hence better spatial resolution.

-> **Four boards** with the same input design were made and tested in a triple-GEM with X-ray beam at BNL. **Data analysis is complete.**
-> The design pushes the PCB manufacturing limit since spaces are below 3 mils (76 um).
-> Produced a foil readout board at CERN to verify that there is no problem for producing high quality zigzag strips on a large-area kapton foil (1 meter scale) at CERN.

Progress @ Florida Tech

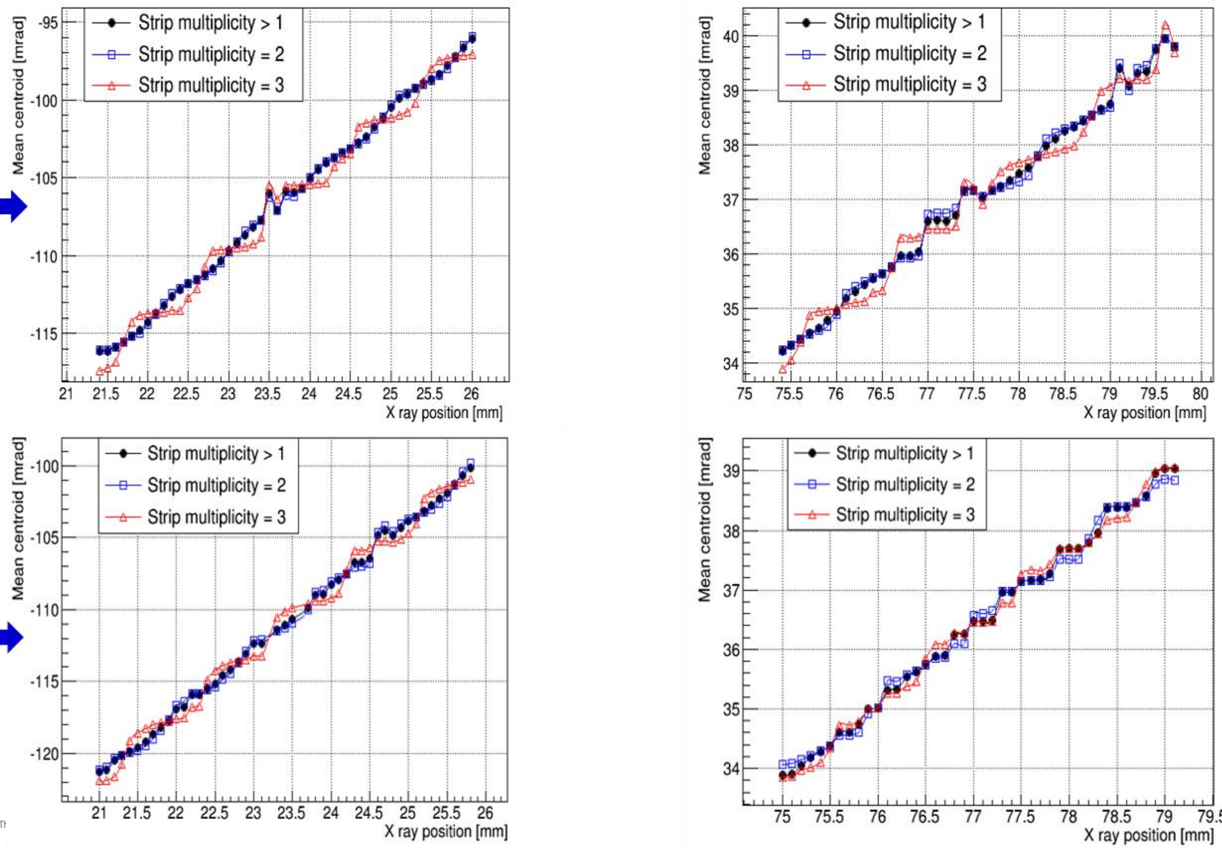
Optimization of the zigzag strip readout design
Results of X-ray scans at BNL

Mean centroid vs. X-ray position

Strip angle pitch **4.14 mrad**, radius in EIC ≈ **229 mm** | Strip angle pitch **1.37 mrad**, radius in EIC ≈ **784 mm**

Best board from PCB comp.

CERN kapton foil board

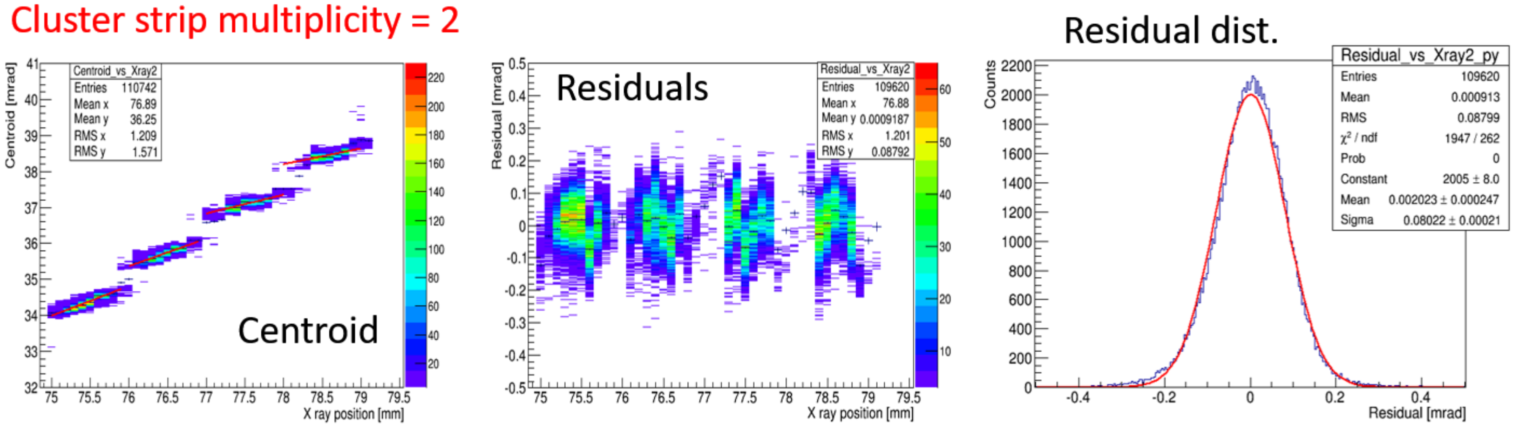


Progress @ Florida Tech

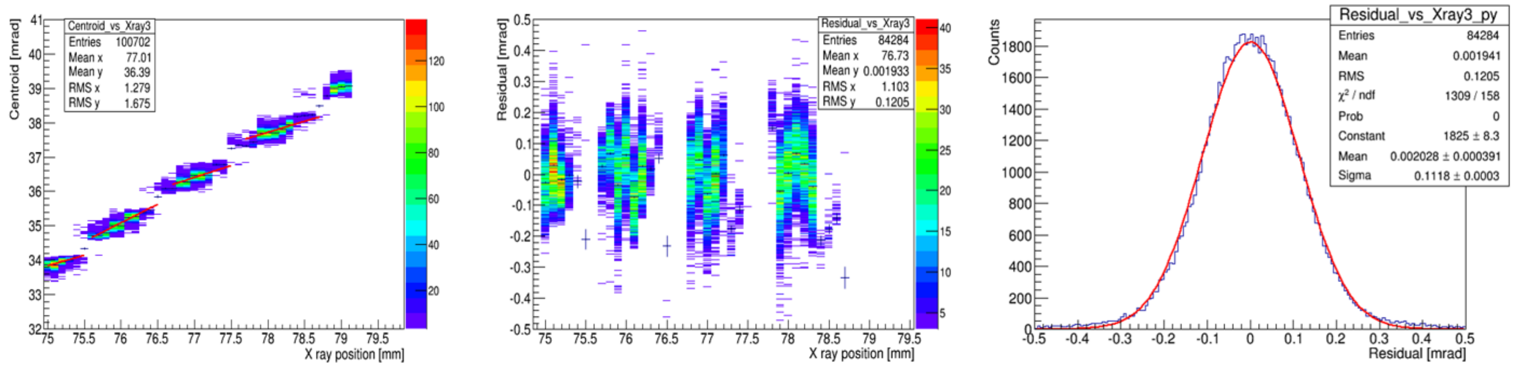
Optimization of the zigzag strip readout design
Results of X-ray scans at BNL

Resolution studies with CERN board for strips with angle pitch 1.37 mrad, radius ≈ 784 mm

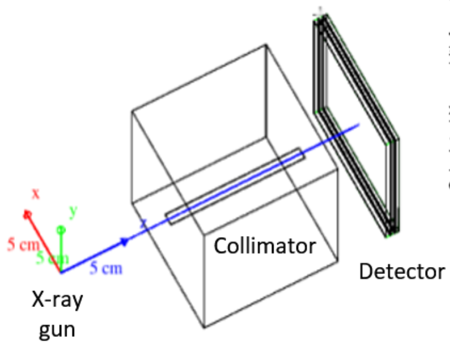
Cluster strip multiplicity = 2

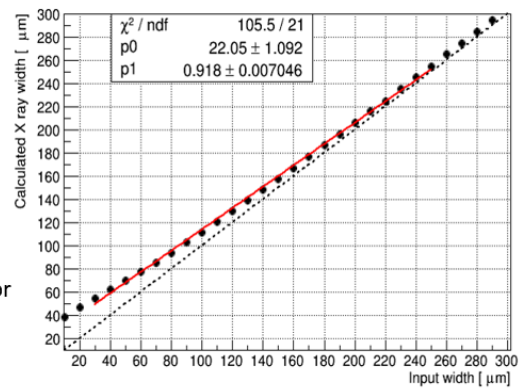


Cluster Strip multiplicity = 3



Optimization of the zigzag strip readout design
Results of X-ray scans at BNL





- The simulation allows subtraction of the effect of the X-ray collimator on the detector resolution. The <u>≈ linear function between measured and intrinsic resolution is used</u> for the correction.
- Actual beam shape (point-like, cone-shape, rectangular, etc.) has insignificant impact.

Final resolution results for all boards (effects due to X-ray collimation are subtracted)

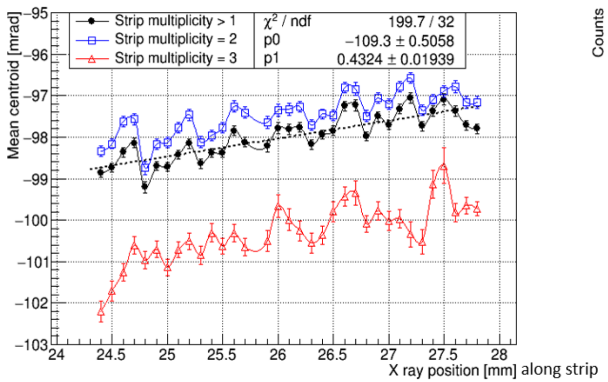
Spatial resolution (µrad/µm)	V_{drift} (V)	Approx. gas gain	Strips with angle pitch 4.14 mrad, r ≈ 229 mm			Strips with angle pitch 1.37 mrad, r ≈ 784 mm		
			2-strip clusters	3-strip clusters	2 & 3-strip cl.	2-strip clusters	3-strip clusters	2 & 3-strip cl.
ACE #1	3380	4000	266 / 61	371 / 85	328 / 75	56 / 44	69 / 54	60 / 47
ACE #2	**3340**	**3000**	**288 / 66**	**480 / 110**	**384 / 88**	**57 / 45**	**97 / 76**	**84 / 66**
ACE #3	3250	1500	-	572 / 131	-	-	140 / 110	-
CERN	**3340**	**3000**	**397 / 91**	**393 / 90**	**397 / 91**	-	-	-
CERN	**3380**	**4000**	-	-	-	**57 / 45**	**92 / 72**	**71 / 56**

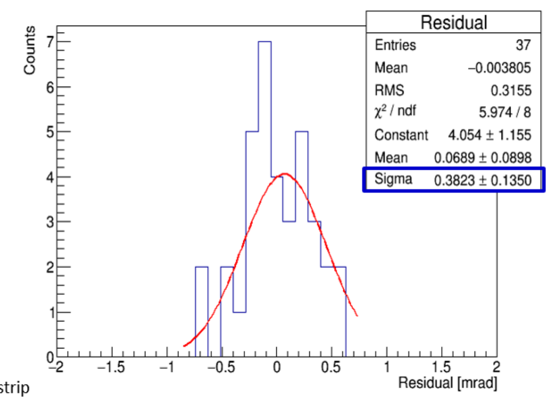
Progress @ Florida Tech

Optimization of the zigzag strip readout design
Results of X-ray scans at BNL

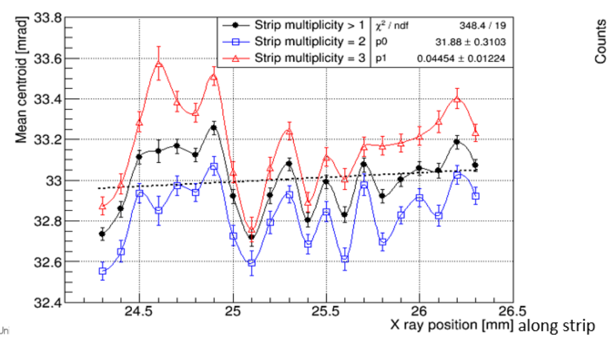
Scans along the radial strip direction – estimate the bias on resolution across strips

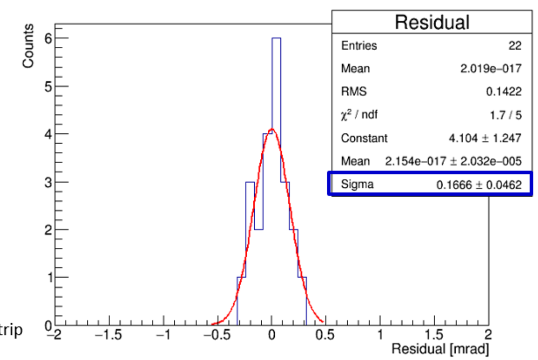
Strip multiplicity > 1 CERN board with strip angle pitch 4.14 mrad: **bias ≈ resolution**





Strip multiplicity > 1





Progress @ University of Virginia

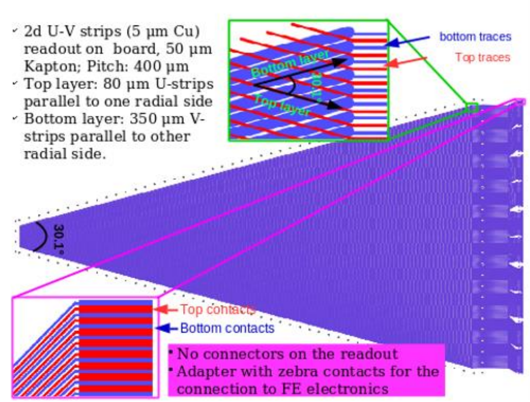
Common GEM foil design:

- ✓ (Univ. of Virginia, Florida Tech, and Temple U.)
- ✓ All connections (HV, gas flow structure and FE cards) are made on outer radius end.
- ✓ We received 4 common GEM foils from CERN

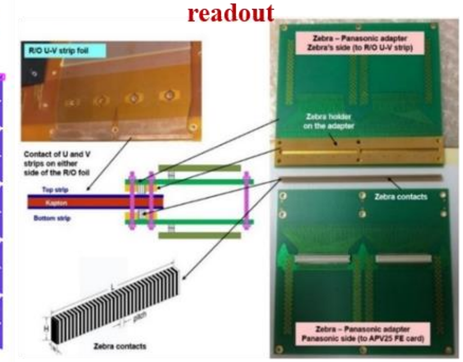
2D U-V strips readout (R/O)

- ✓ Spatial resolution improvement
- ✓ No electronics on active area of the chamber
- ✓ No connectors or metallized vias on R/O
- ✓ Zebra connection for the FE electronics
- ✓ Zebra-Panasonic adapter board

Design of EIC-Proto II 2D U-V strips readout board



Principle of double side zebra connection on flexible PCB readout



Progress @ University of Virginia

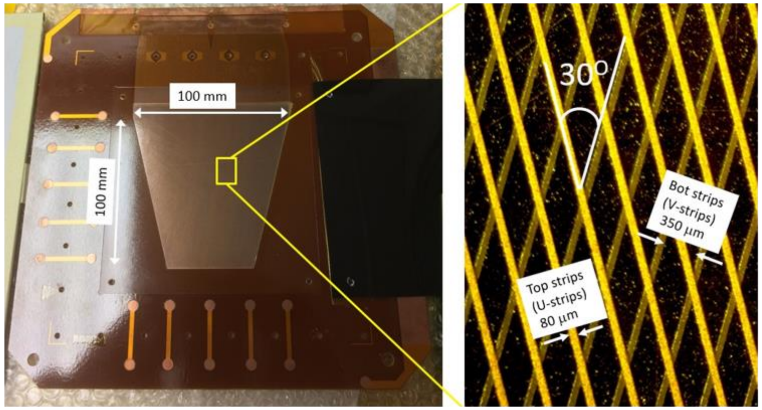
Prototype:

- 10 cm x 10 cm triple GEM
- 2D flexible readout a la COMPASS with U-V strips
- **double side zebra contact**

Goals:

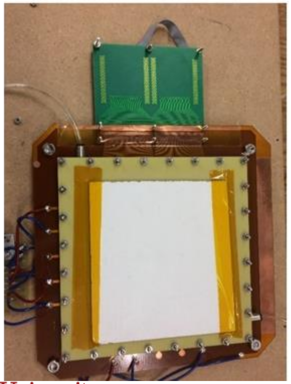
- Spatial resolution study of the new R/O
- **Test double side zebra connection scheme**
- Pedestal noise of the new type of connection

Small readout board with U-V strips structure

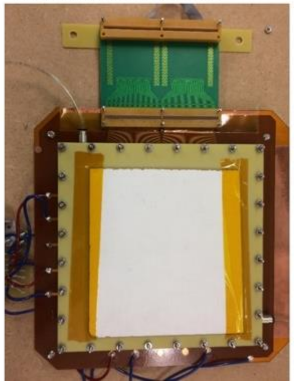


Zebra connection mounted onto the small EIC prototype

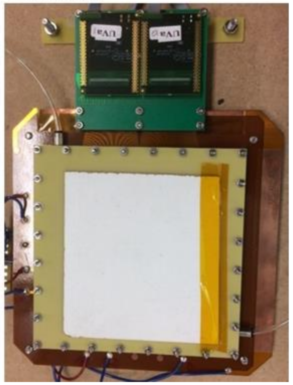
Step 1: The bottom pads of the readout foil are laid on top of the first zebra sitting right on the bottom adapter board



Step 2: Second zebra in its holder frame is stacked on the top pads of the readout foil. U and V strip pads on either side of the Kapton are now sandwiched between top and bottom zebra contacts



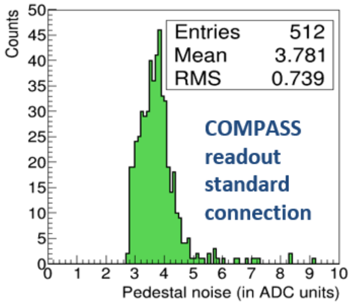
Step 3: Top adapter board is added to completed the scheme. The APV-SRS FE cards are then connected.

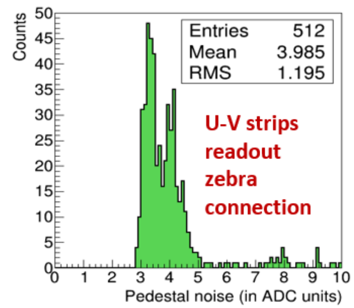


Double side zebra connection scheme offers a simple, low cost and elegant solution to satisfy EIC requirement of avoiding electronics in active area of forward trackers by reading out all the strips of the fine pitch U-V readout on the outer radius side of the chamber

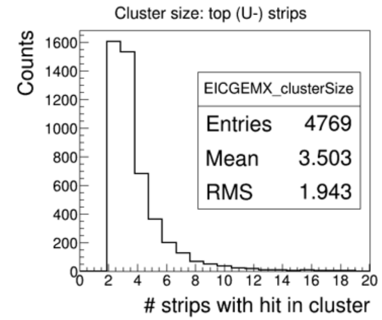
Progress @ University of Virginia

Distribution of pedestal rms (noises) over 512 APV25 chs



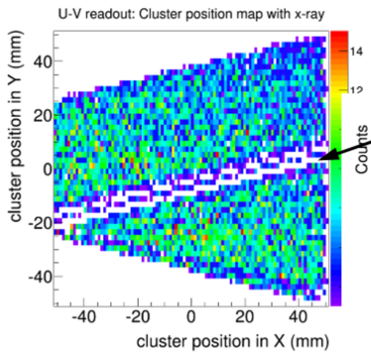


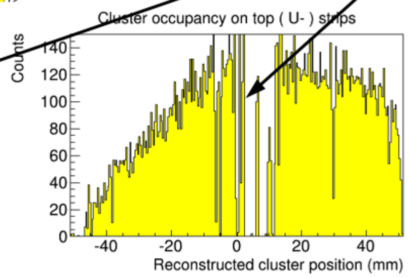
- Pedestal noise level comparable to standard COMPASS 2D readout
- No effect of the zebra connection on noise level



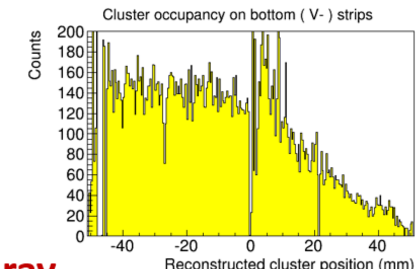
Cluster size > 3.5 ⇨ Expect improvement of resolution

bad zebra contact



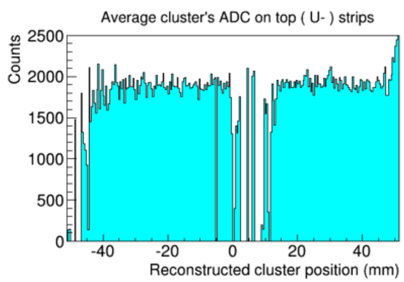


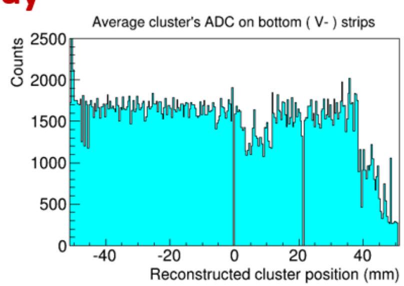
X-ray



Occupancy for U and V strips: Linear dependence with strip length is shown

Uniformity of the gain uniformity: (accumulated ADC / numbers of hits)





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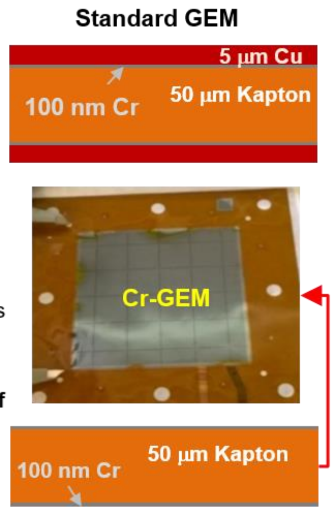
Progress @ University of Virginia

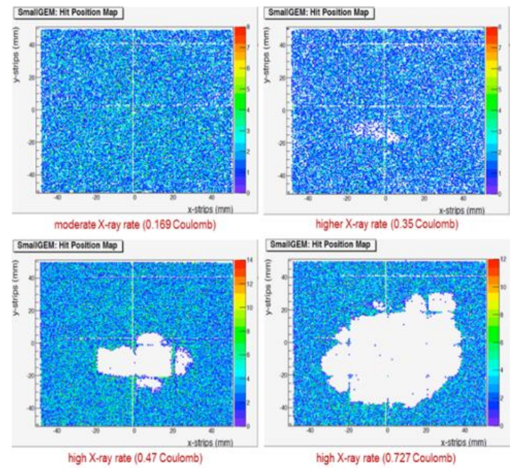
Cr-GEM foil:

- Copper (Cu) raw material comes with 100 nm Chromium (Cr) layer between Cu and Kapton, 5µm Cu layers removed, leave the residual Cr layers as electrodes,
- **Cr-GEM 50% reduction of the material of an EIC triple-GEM detector:**



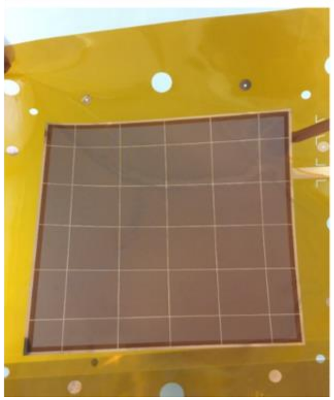
Previous studies: high rate tests with proto I

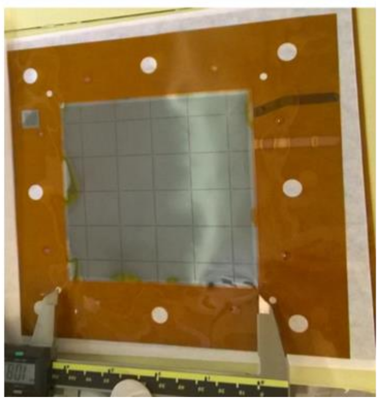
- Exposure to high intensity x-ray ⇨ Degradation observed on third GEM foil only (3rd amplification)
- Evaporation of the bottom Cr layer of 3rd foil ⇨ Dead area on hit map
- **Is the problem created by high rate (gain / discharge related) exposure time (ageing) ? ⇨ Proto II to provide the answer**



new Cr-GEM foil: brown color of the active area

old Cr-GEM: active area has typical silver color of Cr layer





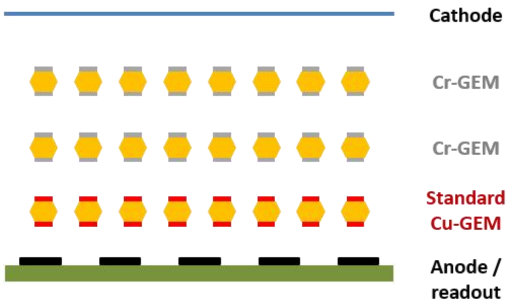
Cr-GEM Proto II: 3 new Cr-GEMs from CERN in Nov. 2016

- Those foils did not have the expected silver color of Cr GEM
- **Cr layer likely removed during copper etching**
- The foils fail electrical test, attempt to get signal with cosmic or x-ray unsuccessful
- CERN PCB workshop agrees to replace the bad foils, they are investigating the issue

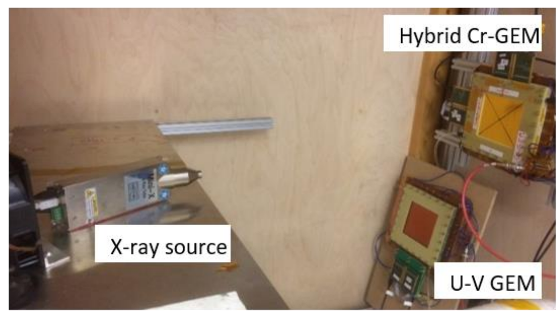
Progress @ University of Virginia

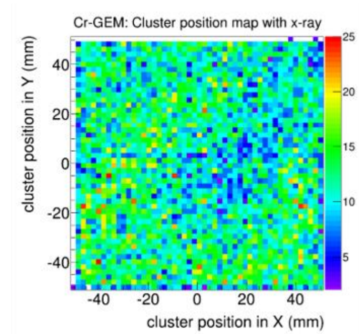
Hybrid Cr-GEM chamber: Use Cr-GEMs for first 2 amplification and standard GEM (with Cu) for the third

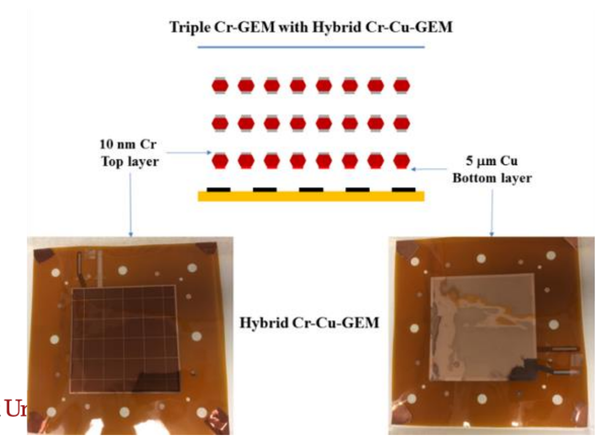
- Exposure of hybrid Cr-GEM chamber to moderate rate with the x-ray source for weeks
- Daily monitoring chamber performance with ^{90}Sr source,
- Basics characteristics i.e. cluster size, relative gain, gain uniformity



X-ray setup with Cr-GEM & U-V readout GEM







Plans for the future:

- Build new prototypes one only Cr-GEM, and combination of 2-Cr-GEM and **Cr-Cu-GEM** foil (picture on the left).
- Repeat the aging studies for **the two new triple Cr-GEM chambers**
- Optical scan with Temple U's GEM CCD scan setup **(B. Surrow eRD3)**
- Investigate the possibility of SEM microscopy for GEM holes cross section measurement

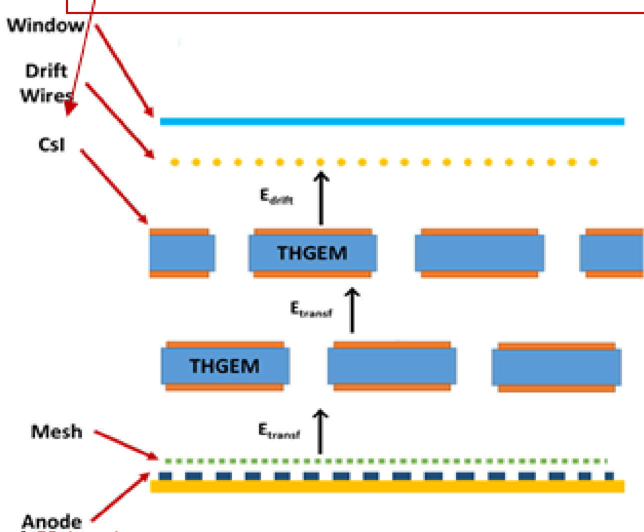
Startup @ INFN Trieste

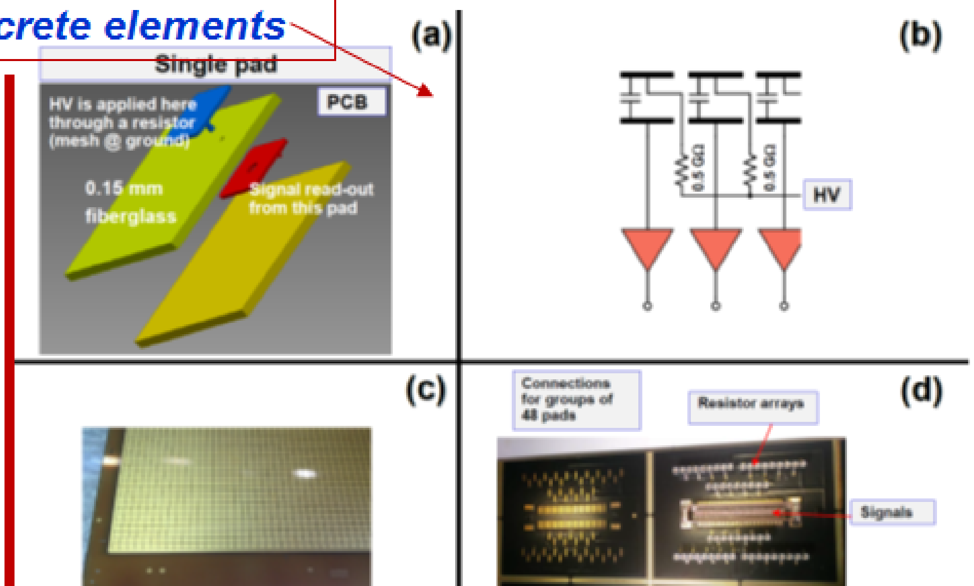
- **GOAL:**

  further improvements of the hybrid (= 2 (TH)GEMs + 1 MICROMEGAS) MPGD for single photon detection for

  - **PID, in particular high momentum RICHes**
  - **Synergies with TPC sensors by MPGD technologies**

The starting status:
- ***Scheme of the detector architecture***
- ***The resistive anode by discrete elements***





Startup @ INFN Trieste

- **TASKS (3-year program):**
  - RICH specific: test of novel materials for THGEM substrate to simplify the detector construction, increase the yield of valid large-size THGEMs and, thus, control the detector costs;
  - Also SYNERGIC with TPC: the development of resistive MM by discrete elements with miniaturized pad size (present size: 8 x 8 mm^2) in order to obtain finer space resolution; Synergic with TPC sensor development
  - RICH specific: comparison of THGEM vs GEM photocathodes in order to select the best architecture for the photon detectors of the EIC RICH;
  - Also SYNERGIC with TPC: further studies in order to enhance the IFB suppression in hybrid MPGDs;
  - RICH specific: operation of hybrid MPGDs (THGEMs + MM) in fluorocarbon-rich gas mixtures.

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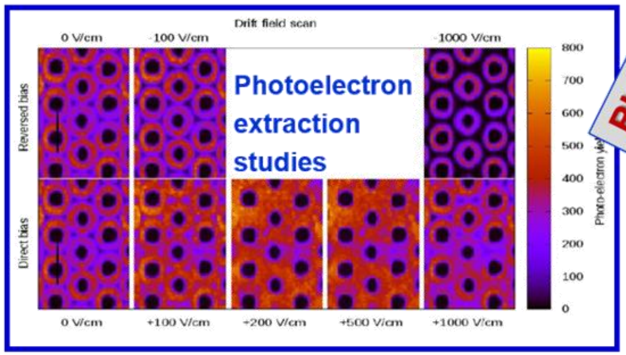
Startup @ INFN Trieste

resistive MM
with small
pad size
O(100 mm²)
→
O (10 mm²)

Also SYNERGIC with TPC

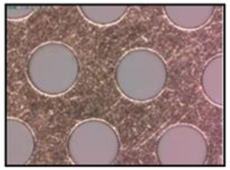
Further reduction of the Ion BackFlow (IBF) rate:
presently ~ 5%

GEM vs THGEM as photocathodes



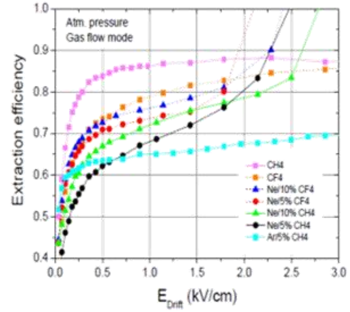
RICH specific

Investigation of alternative THGEM substrate material for improved performance/yield



Issues related to hybrid MPGD-based PDs operated in C-F atmosphere:

- photolelectron extraction
- Detector gain
- ageing



Startup @ INFN Trieste

- **Both tasks 1 and 2 have started:**

  1. A THGEM by PERMAGLAS has been fully characterized
  2. The design of a MICROMEGAS anode with 3 x 3 mm^2 size is ongoing

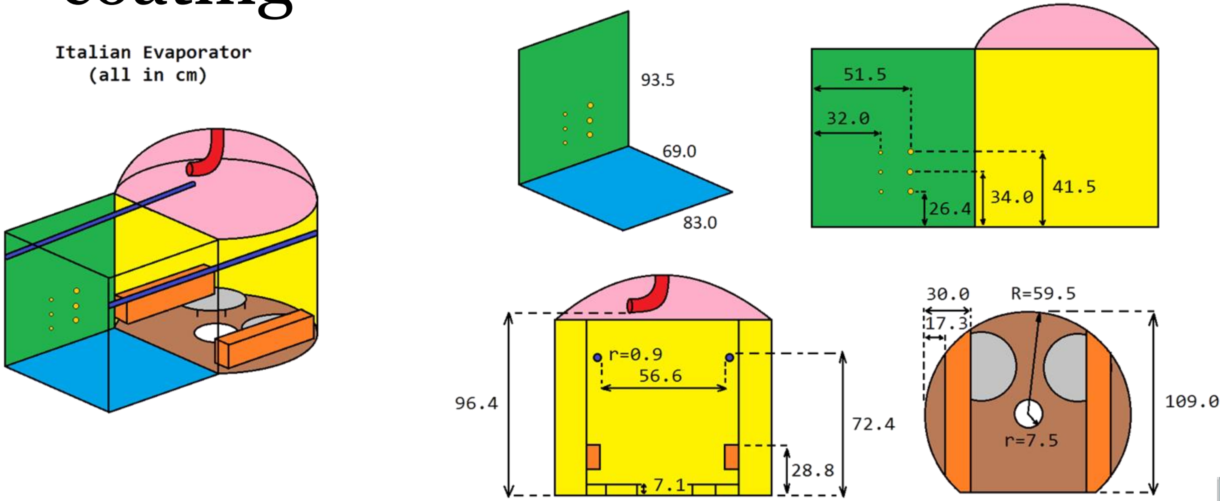
		FY 2017				FY 2018				FY 2019			
TASK no	TASK	1st quarter	2nd quarter	3rd quarter	4th quarter	1st quarter	2nd quarter	3rd quarter	4th quarter	1st quarter	2nd quarter	3rd quarter	4th quarter
1	test of novel materials for THGEM												
2	resistive MM by discrete elements with miniaturized pad size												
3	comparison of THGEM vs GEM photocathodes												
4	enhancement of the IFB suppression in hybrid MPGDs												
5	operation of hybrid MPGDs (THGEMs + MM) in fluorocarbon-rich gas mixtures												

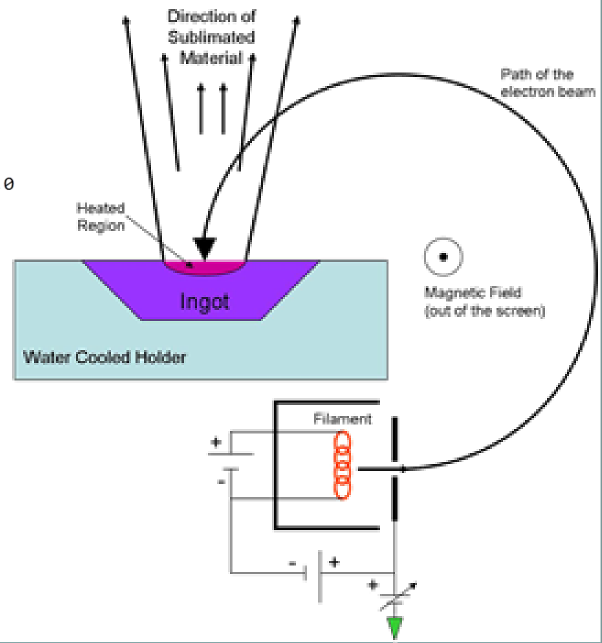
Progress @ Stony Brook

- Preparation of “INFN evaporator” for large mirror coating started

Progress @ Stony Brook

- Preparation of "INFN evaporator" for large mirror coating





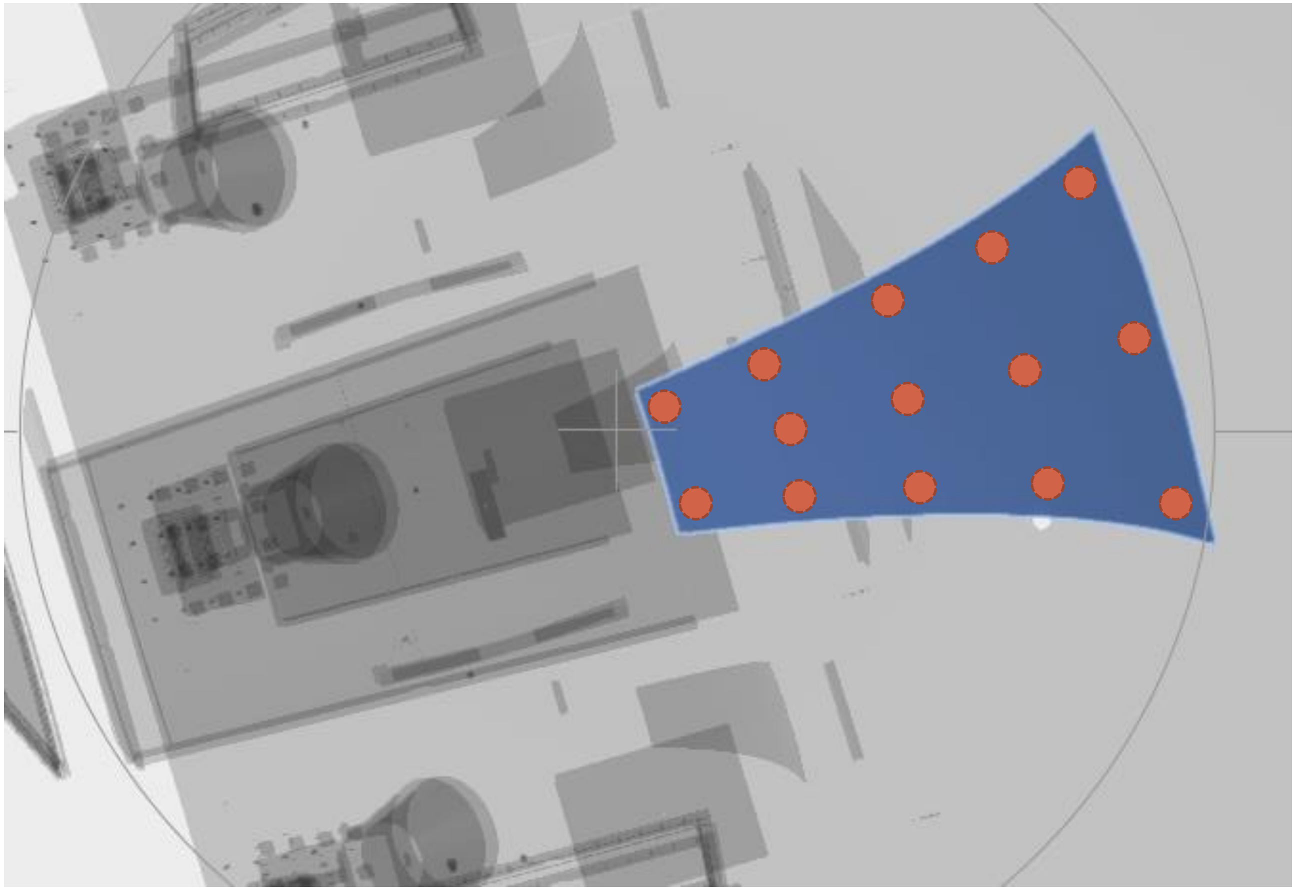
Progress @ Stony Brook

- We are acquiring
  - Electron gun
  - Ion gun
  - Power supplies
  - Thickness monitors
  - Mirror mounting structure
  - Ion gun → smoothen surface
    - Coating to be ~ hundreds of Å , controlled to the level of ~ tens of Å → "hammer" bumps away

Progress @ Stony Brook

Progress @ Stony Brook

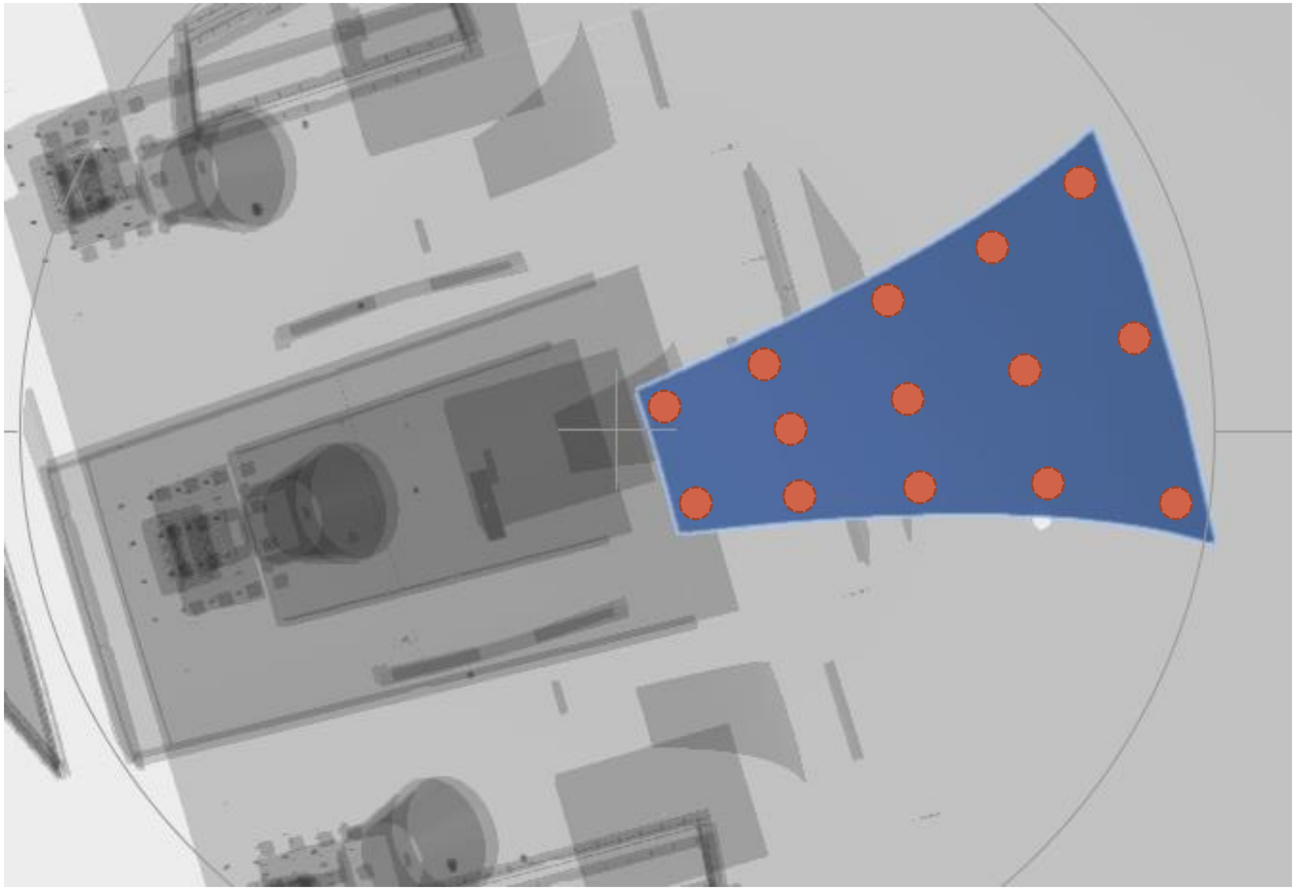
- Position small sample blanks at strategic places



Stony Brook University

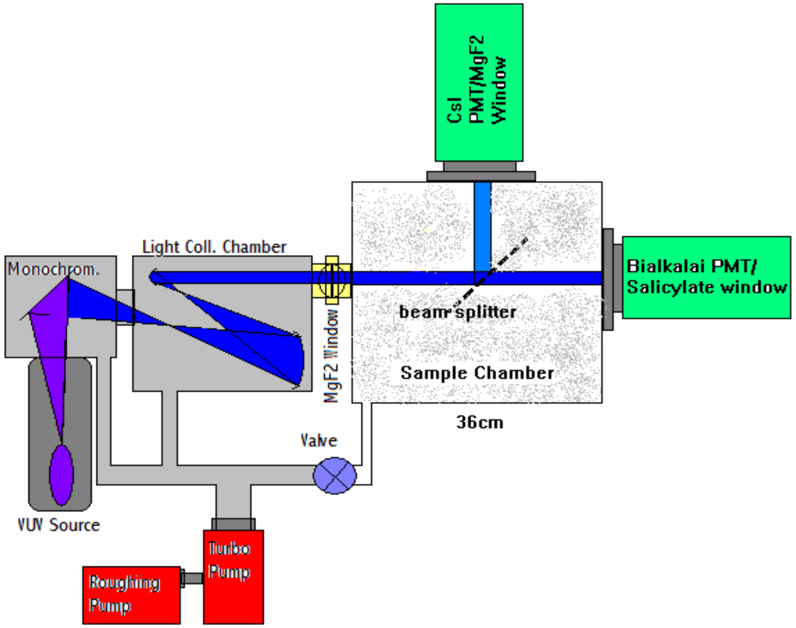
Progress @ Stony Brook

- Coat each blank with Al/MgF_2



Progress @ Stony Brook

- Spectral analysis of each sample mirror



Progress @ Yale University

- Analysis of 3-D coordinate GEM completed
- Hybrid gain structure for TPC readout
  - Two GEMs + MicroMegas → possible minimization of Ion Backflow IBF
  - Measurements with different readout plane geometries and different gas mixtures performed

Summary

- Continued progress at all fronts in eRD6 project
- Phasing out generic R&D
- New international collaborator starting up
- Funding for all other groups ceased
  - Targeted R&D projects stalled
- Request to the committee for next funding cycle
  - Institutions and their requests to be listed in funding summary table
  - Priority list accordingly

Published Results

- All groups published in peer-reviewed journals
  - BNL
    1. Manuscript in preparation: "First Results from a Prototype Combination TPC Cherenkov Detector with GEM Readout", to be submitted to the IEEE Transaction on Nuclear Science in early 2017, see Stony Brook publications
    2. Oral presentation at the IEEE NSS/MIC conference in Strasbourg, France in November 2016 on the TPC/Cherenkov hybrid detector, see Stony Brook publications
    3. B. Azmoun et al., "A Study of a Mini-drift GEM Tracking Detector ", IEEE Trans. Nucl. Sci. Vol. 63, No.3, June 2016, pp. 1768-1776.
    4. C. Woody et. al.: "A Prototype Combination TPC Cherenkov Detector with GEM Readout for Tracking and Particle Identification and its Potential Use at an Electron Ion Collider", Conference Proceedings of the 2015 Micropattern Gas Detector Conference, Trieste, Italy, October 12-15, 2015.
    5. M.L. Purschke, "Test Beam Study of a Short Drift GEM Tracking Detector" Conference Record Proceedings of the 2013 IEEE Nuclear Science Symposium and Medical Imaging Conference, October 27-Nov 2, 2013, Seoul, Korea

Published Results

- All groups published in peer-reviewed journals
  - [INFN Trieste]
    Just started, N/A

Published Results

- All groups published in peer-reviewed journals
  - Florida Institute of Technology

1. A. Zhang and M. Hohlmann, "Accuracy of the geometric-mean method for determining spatial resolutions of tracking detectors in the presence of multiple Coulomb scattering," JINST 11 P06012 (2016), June 21, 2016; preprint version arXiv:1604.06130, Apr 20, 2016.
2. A. Zhang, et al., "Performance of a large-area GEM Detector read out with wide radial zigzag strips," Nucl. Inst. Meth. A 811 (2016) 30-41, online version at ScienceDirect (18 Dec 2015); preprint version arXiv:1508.07046, Aug 2015.
3. A. Zhang, V. Bhopatkar, M. Hohlmann, et al., "R&D on GEM Detectors for Forward Tracking at a Future Electron-Ion Collider", Proc. of IEEE Nuclear Science Symposium 2015, San Diego, CA; arXiv:1511.07913, Nov 24, 2015.
4. A. Zhang, et al., “Study of non-linear response of a GEM detector read out with radial zigzag strips,” in preparation for submission to NIM A and presented as a poster at the 2016 IEEE NSS, Strasbourg, France.
5. M. Bomberger, et al., “Mechanical design and stress analysis of a large-area gas electron multiplier,” in preparation for submission to Journal of Mechanical Design (JMD). This work has also been submitted to the Florida Academy of Sciences (FAS) annual meeting in 2017.

Published Results

- All groups published in peer-reviewed journals
  - Stony Brook University
    1. M. Blatnik et al., "Performance of a Quintuple-GEM Based RICH Detector Prototype", IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 62, NO. 6, DECEMBER 2015.
    2. M. Blatnik et al., "Performance of a Quintuple-GEM Based RICH Detector Prototype", Nuclear Science Symposium Conference Record, 2015, IEEE
    3. Manuscript in preparation: "First Results from a Prototype Combination TPC Cherenkov Detector with GEM Readout", to be submitted to the IEEE Transaction on Nuclear Science in early 2017, see BNL publications
    4. Proceedings in preparation: "First Results from a Prototype Combination TPC Cherenkov Detector with GEM Readout", for the IEEE NSS/MIC 2016 in Strasbourg, see BNL publications

Published Results

- All groups published in peer-reviewed journals
  - University of Virginia
    1. K. Gnanvo, et al., "Large Size GEM for Super Bigbite Spectrometer (SBS) Polarimeter for Hall A 12 GeV program at JLab", Nucl. Inst. and Meth. A782, 77-86 (2015). *DOI: 10.1016/j.nima.2015.02.017*
    2. K. Gnanvo et al., "Performance in Test Beam of a Large-area and Light-weight GEM detector with 2D Stereo-Angle (U-V) Strip Readout", Nucl. Inst. and Meth. A808 (2016), pp. 83-92. *DOI: 10.1016/j.nima.2015.11.071*

Published Results

- All groups published in peer-reviewed journals
  - Yale University
    1. S. Aiola et al., “Combination of two Gas Electron Multipliers and a Micromegas as gain elements for a time projection chamber”, Nucl. Inst. and Meth. A834 (2016) 149-157.